J. agric. Engng Res. (1987) **38,** 227–243

Microcomputer-based Tractor Performance Monitoring and Optimization System*

J. GROGAN†; D. A. MORRIS†; S. W. SEARCY‡; B. A. STOUT‡

A tractor performance monitoring and optimization project was conducted in the United States to document tractor use on commercial farms and to improve tractor fuel efficiency. A two-wheel drive diesel tractor was instrumented to measure engine load, engine speed, wheel slip, fuel consumption, draught, and hitch forces. An on-board microcomputer monitored and recorded tractor performance. The microcomputer could also optimize tractor performance by recommending to the operator the optimum gear and throttle setting to achieve maximum fuel efficiency.

Commercial farmers operated the instrumented tractor on their farms just as they operated their own tractors. Farmers typically ran the tractor at full throttle under light to moderate loads. Analysis indicated that farmers could have reduced fuel consumption 15–27% by practising "shift-up, throttle-back"; i.e. by shifting to a higher transmission gear and reducing the engine speed to maintain a nearly constant forward travel speed. Actual fuel consumption dropped from 11·3 to 20·0% in controlled field tests using a tractor operator information feedback system.

1. Introduction

Tractor performance monitors measure, record, and sometimes display information about tractor operation. Operating parameters frequently monitored include tractor power, fuel consumption, draught, and wheel slip. Tractor performance optimization seeks to improve tractor operation by adjusting one or more of these parameters.

Tractor performance monitoring and optimization has recently received increased attention. Matthews[1] reported that tractors and other field machines accounted for approximately 25% of total energy taken by farms in the UK (excluding chemicals and machinery production) or about 37% of the petroleum fuel energy. While tractors consume a large portion of farm energy supplies, studies in the United States indicate that farmers do not use tractors efficiently.[2,3] Larsen[3] reported that even for heavy field operations, Montana farmers use only 60% of the rated engine capacity. He found that farmers were not practising shift-up, throttle-back, i.e. they were not operating the tractors in the highest possible gear and reducing engine speed to reduce fuel consumption. Shift-up, throttle-back (s.u.t.b.) improves engine efficiency by maintaining high engine load and engine speed in the range of 60 to 80% of rated speed. Zoerb and Kushwaha[4] found the fuel savings and improvements in tractive efficiency were "significant" using s.u.t.b. with two-wheel and four-wheel drive tractors in Canada. In South Africa, Lyne *et al.*[5] found that by optimizing engine performance and tractive efficiency, fuel consumption could be minimized while maintaining high levels of power output.

A tractor performance monitoring and optimization (t.p.m.o.) project is being conducted at Texas A & M University (TAMU) to document tractor use and to improve tractor performance on Texas farms. The specific objectives of the project are to:

(1) document tractor performance and load use cycles on Texas farms;

---

* Approved for publication as Technical Article No. TA-20318 of the Texas Agricultural Experiment Station

† Dohner & Associates, Dohner & Associates, Inc., 5100 Academy Drive, Suite 100, Lisle, IL 60532, USA
‡ Agricultural Engineering Department, Texas A & M University, College Station TX 77843–2117, USA

Received 28 February 1985; accepted in revised form 28 April 1987

0021–8634/87/120227 + 17 $03.00/0

(2) provide information feedback to the operator that will assist in improving overall tractor performance; and
(3) evaluate the fuel savings and economic benefits resulting from information feedback.

The t.p.m.o. project was divided into three phases:

(1) instrument a John Deere 4440 tractor to measure draught, ground speed, wheel slip, fuel consumption, and engine load;
(2) develop a microcomputer based on-board tractor performance monitor to measure, display, and record the operating parameters; and
(3) add an information feedback system to the microcomputer that would help the operator optimize engine efficiency based on the shift-up, throttle-back principle.

Phases 1 and 2 have been completed and extensive tests have been conducted on commercial farms. The feedback system has been developed, and has been tested both with commercial operators and in controlled field tests.

2. Literature review

Instruments to measure tractor field performance have existed since the early 1900s. Extensive reviews of equipment used to measure and monitor tractor performance have been made by Langeswich,[6] Grevis-James,[7] and Green.[8] Research emphasis in recent years has been on the development of computer-based monitors and optimization systems.

2.1. *Computer-based tractor monitors*

Luth *et al.*[9] described a sophisticated microcomputer telemetry system used in acquiring field data. The system had an input capability of 31 channels and could scan up to 50 000 samples per second. Data were processed in the field at a mobile receiving station where outputs were immediately displayed, printed, or graphed.

Grevis-James *et al.*[10] used two AIM-65 microcomputers to monitor, record, and analyse tractor operation. The first computer monitored and recorded drawbar pull, ground speed, wheel slip, fuel flow, and engine speed. The recorded data were transferred to the second computer to be analysed and printed.

Tompkins and Wilhelm[11] described a system that could vary the sampling rate from 0·01 s to 4·5 min. Operator control was through a keyboard and video monitor located inside the tractor cab. Extensive software programs were developed for system checks, testing, and data collection.

Carnegie *et al.*[12] programmed a personal computer to monitor ground speed, wheel speed, axle torque, draft, and fuel consumption. They concluded that using personal computers for tractor performance monitoring is inexpensive and minimizes development time.

Harter and Kaufman,[13] Lin *et al.*,[14] Wendte and Rozeboom,[15] Hohenberger and Alexander,[16] Hendrix *et al.*,[17] Reynolds *et al.*,[18] Stange *et al.*,[19] and others also developed computer-based performance monitors.

2.2. *Tractor optimization monitors*

Some tractor monitors are used to optimize one or more aspects of tractor performance, such as engine efficiency and tractive efficiency. Bloome and Grevis-James[20] divided tractor optimization monitors into three categories:

(1) information monitors, which display information about tractor operation and let the operator act accordingly;

(2) command monitors, which suggest to the tractor operator appropriate action to improve tractor performance; and
(3) control monitors, which automatically adjust tractor operation to improve performance.

Most current monitors are information monitors. Command monitors have been developed by Schrock *et al.*[21] and Grogan *et al.*[22] A comprehensive control monitor has not yet been introduced, but these monitors appear most promising for commercial production because they reduce, rather than increase, the decision load on the tractor operator.

2.2.1. *Information monitors*

Clark and Gillespie[23] described an information monitor that displayed an efficiency number based on inputs of travel speed, fuel consumption rate, and draft. Using this method, the operator could adjust engine speed and gear setting to achieve the highest efficiency number.

Meiring and Rall[24] used measurements of engine speed and injector pump governor control arm position to determine best fuel efficiency. An analogue meter indicated to the operator the point of best fuel efficiency.

Mertins and Gohlich[25] described an efficiency monitor that measured fuel consumption rate and ground speed. The monitor display presented a graph of cost versus work rate, and a light emitting diode indicated the actual working point.

Renault Agriculture[26] developed an efficiency monitor known as the Ecocontrol. This monitor measured engine speed and exhaust gas temperature and then related them to engine performance. The face of the monitor consisted of two needles that crossed over a pattern designating various operating zones of the engine. The operating point of the engine was represented by the intersection of the two needles. The operator adjusted engine speed and transmission gear to keep the intersection of the two needles within a designated operating zone.

2.2.2. *Control monitors*

Ismail *et al.*[27] developed a slip control monitor that maintained wheel slip in a specified range by adjusting implement depth.

Chancellor and Thai[28] built an automatic gear and engine speed control system based on axle torque and ground speed. The controller used hard-wired digital logic (no microprocessor) to select the optimum gear and engine speed setting for efficient tractor operation. The project demonstrated the potential for microprocessor-based gear and engine speed control in tractors.

Harmon and Struthers[29] developed a microprocessor-based gear control system for the heavy-duty automatic transmissions used in trucks and earth-moving equipment. The benefits of intelligent gear control included better fuel efficiency, overall performance, reliability, and durability than could be achieved with conventional hydraulic transmission controls. Similar principles could be applied for intelligent gear control in agricultural machinery.

3. Instrument package

The tractor instrument package measured axle torque, engine speed, draught, fuel consumption, front and rear wheel speed, differential gear speed, radar ground speed, three-point hitch forces and position. The instrument package was installed on a John Deere 4440 tractor loaned to the t.p.m.o. project by Deere and Company. The instrumented tractor (*Fig. 1*) was described in detail by Green.[8]

Fig. 1. Instrumented tractor with bedding implement. Axle strain gauge signals are transmitted by cables attached to arms on either side of rear axles. Note microcomputer to the left of operator seat. Terminal (above computer) is used by research personnel to communicate with the computer

Axle torque was measured with strain gauges mounted on the right and left rear axles. The analogue voltage signals from the axles provided an indication of engine load.

Engine speed was measured with an electronic tachometer that produced a frequency signal proportional to engine speed. This tachometer was mounted between the existing mechanical drive sender and the tachometer cable leading to the operator's console.

Draught was measured with a strain-gauge proving ring load cell mounted on the front end of the drawbar. The load cell produced a voltage signal varying between −25 mV and +25 mV which was proportional to the load. The range of the load cell was 0 to 45 kN and the output signal could be read with a resolution of 0·039 kN.

Fuel consumption was measured with a positive displacement flowmeter. The flowmeter used a four-piston flow transducer and a transmitter to generate a two-phase frequency signal proportional to flow. A totalizer converted the frequency signal to binary coded decimal (b.c.d.) representation.

Wheel speed was measured with toothed gears and magnetic pickups that generated frequency signals proportional to rotational speed. The right front and right rear wheel speeds were measured to determine drive wheel slip.

Differential gear rotational speed was measured to determine the average rear wheel speed, thus allowing the left rear wheel speed to be calculated. A magnetic pick-up located over the final drive reduction gear in the differential generated a frequency signal proportional to the gear's rotational speed.

Ground speed was also measured with Doppler radar. A DICKEY-john TPMII radar unit, mounted about midway on the right side of the tractor frame, generated a frequency signal proportional to ground speed. The radar unit was calibrated at the factory and was checked by a series of timed speed trials in the field. The sensor generated an output signal with a frequency of 47 Hz/m.p.h. or 100 pulses per metre of travel. The manufacturer's specifications designated ±3% accuracy.

Three-point hitch position and forces were measured with a three-point hitch dynamometer. Strain gauge load cells mounted in the existing hitch linkages measured vertical, horizontal, and side forces in the hitch. A string potentiometer measured hitch position. The strain gauges and the string potentiometer generated analogue voltage signals.

4. Microcomputer system

The microcomputer system (*Figs 2* and *3*) was described in detail by Morris *et al.*[30-32] and was designed to achieve the following objectives:

(1) measure, process, display, and record analogue, digital, and frequency signals from the sensors;
(2) store data from extended periods of tractor operation and retain data when the tractor is not running;
(3) operate reliably when exposed to vibration, dust, and extremes in temperature and humidity;
(4) require little or no attention from the tractor operator, nor interfere with normal tractor operation; and
(5) be amenable to functional changes, e.g. changes made frequently should not require hardware or software modification; allowances for future expansion should be provided as well.

The system development was divided into two areas: hardware and software.

4.1. *Hardware*

The microcomputer system hardware was composed of a power supply, a computer enclosure, the microcomputer, a terminal and a tape recorder.

4.1.1. *Power supply*

The computer was powered by the tractor's 12 V battery. A time delay relay, triggered by the ignition switch, automatically turned the computer on and off. The time delay allowed voltage spikes occurring during engine start-up to dissipate before power was

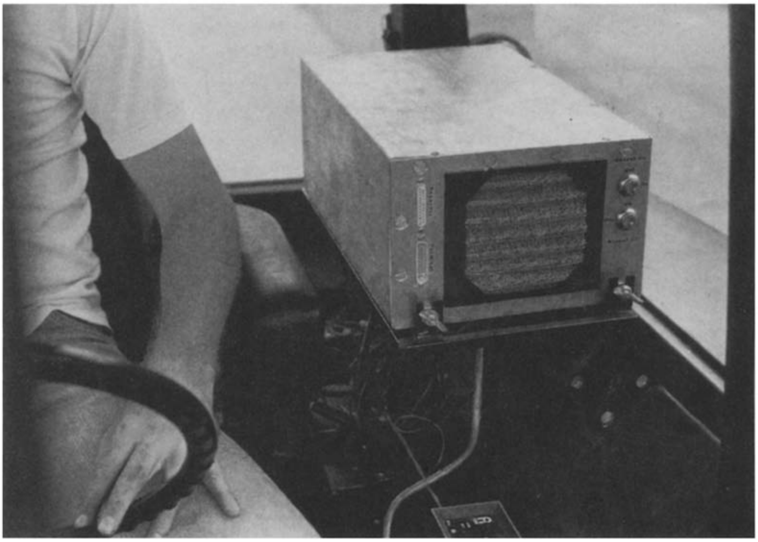


Fig. 2. Microcomputer mounted beside tractor operator in cab

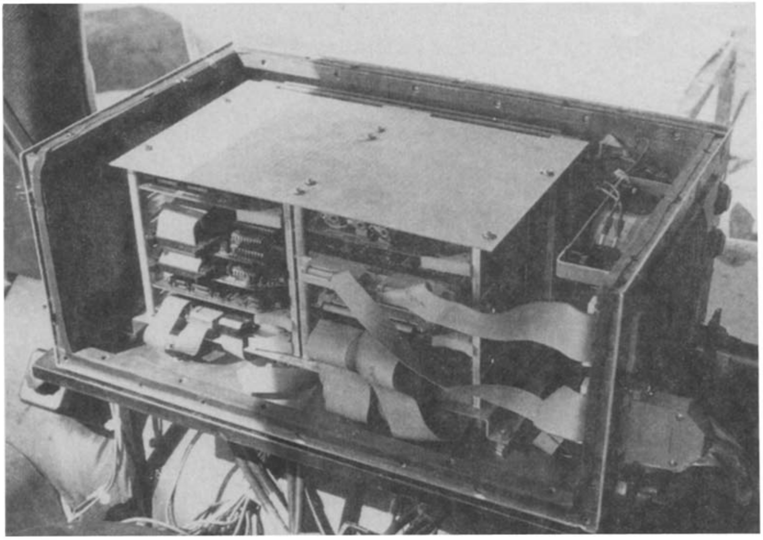


Fig. 3. Exposed view of microcomputer

supplied to a d.c./d.c. converter. This device supplied regulated voltage at ±12 V and +5 V to the computer.

4.1.2. *Enclosure*

An aluminium enclosure housed the computer cards arranged in a 12-slot card cage. A positive pressure d.c. fan, with filters, provided cooling and maintained a dust-free environment. The computer was located inside the tractor cab to the left of the operator's seat where it did not interfere with the operator's vision or freedom of movement.

4.1.3. *Microcomputer*

The microcomputer was composed of ten STD-BUS cards, each with a particular function. A block diagram of the computer is shown in *Fig. 4* and a brief description is provided below.

The central processing unit (CPU) was a MC6800 microprocessor, which was located on a central processor card along with eight kilobytes (kbytes) of erasable programmable read-only memory (EPROM) and up to four kbytes of random access memory (RAM). The CPU was the computer "brain" and interfaced to the tractor through the other cards. The clock-calendar card maintained the time and date for the computer.

The input/output (i/o) timer, analogue/digital (a/d) converter, and counter cards interfaced to the tractor instrumentation. The i/o timer monitored digital signals, the a/d monitored analogue voltage signals, and the counter monitored frequency signals. The i/o timer was also used to initiate signal scans. The RAM/ROM card was populated with 12 kbytes of additional (EPROM) memory, plus 8 kbytes for the voice board vocabulary.

The bubble memory system, composed of two cards, was the computer data storage device. The bubble memory provided 256 kbytes of non-volatile data storage, and could have been expanded up to four megabytes (Mbytes) of memory by adding additional bubble memory cards.

Some advantages the bubble memory system had over traditional data storage systems, such as floppy disks or tape recorders, were:

(1) rapid data transfer;

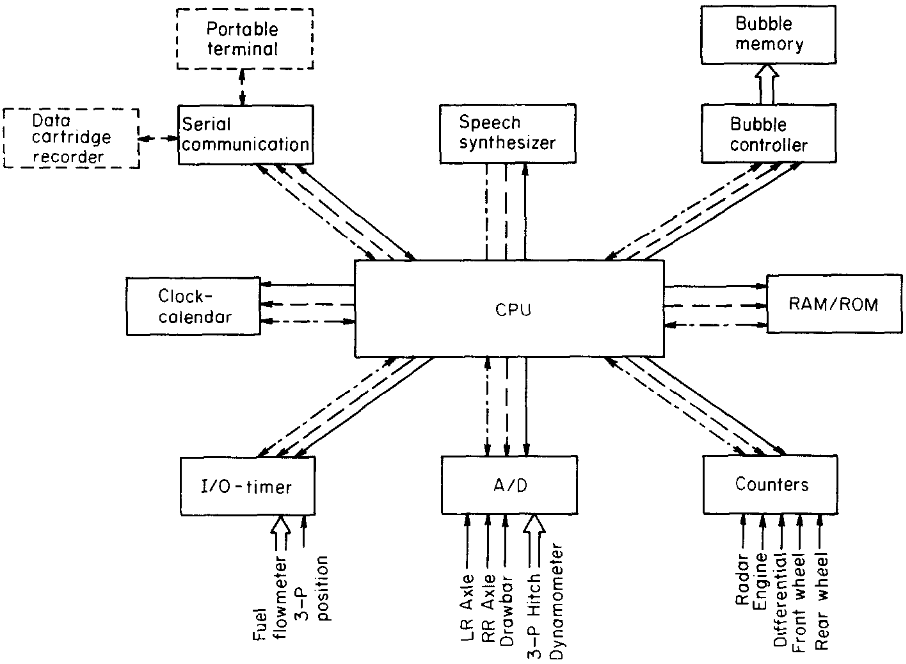


Fig. 4. Microcomputer block diagram. ——, *Control bus;* ——, *address bus;* – – – – –, *data bus;* — — —, *RS232*

(2) high density storage that contained over 30 h of tractor operating data; and
(3) claimed higher tolerance to dust, heat, and vibration than mechanical data storage device, a claim that seems justified by experience to date.

The speech card enabled the computer to "talk" to the tractor operator in computer-assembled pre-programmed words and phrases. The card was used as part of the information feedback system. Searcy and Ahrens[33] described the development and operation of the speech card. The serial communications card allowed the CPU to communicate with a terminal and a tape recorder.

4.1.4. *Terminal*

A portable terminal, with a two-line, 64-character liquid crystal diode display, allowed research personnel to interact with the computer (*Fig. 5*). The terminal was also used as a message display for the information feedback function of the project.

4.1.5. *Data cartridge recorder*

This high-speed tape recorder was used to transfer recorded data from bubble memory to magnetic tape (*Fig. 6*). The data cartridge recorder could be controlled by the computer, from a terminal, or with manual switches on the recorder's front panel.

4.2. *Software*

The t.p.m.o. software was designed to perform four primary functions: start the computer; acquire data; optimize tractor performance; and interact with research personnel. To achieve

Fig. 5. Portable terminal used to communicate with the microcomputer

project overall objectives the software was required to have the operating characteristics noted in the computer design objectives. All software was written in assembly language.

4.2.1. *Start*

"Start" initialized the computer when it was powered-up. After initialization, "Start" scanned the instrument signals for faults and performed a diagnostic test on bubble memory, then recorded the results. Self-diagnostics were particularly useful since the computer was not manually inspected when the tractor was started.

4.2.2. *Data acquisition*

The data acquisition program had to acquire and record operating data while conserving memory space. Two different scanning procedures were used: one for the instantaneous analogue signals, and another for the integrating frequency counters, fuel flow, and implement position. Typically, analogue signals were scanned at 100 Hz and were averaged

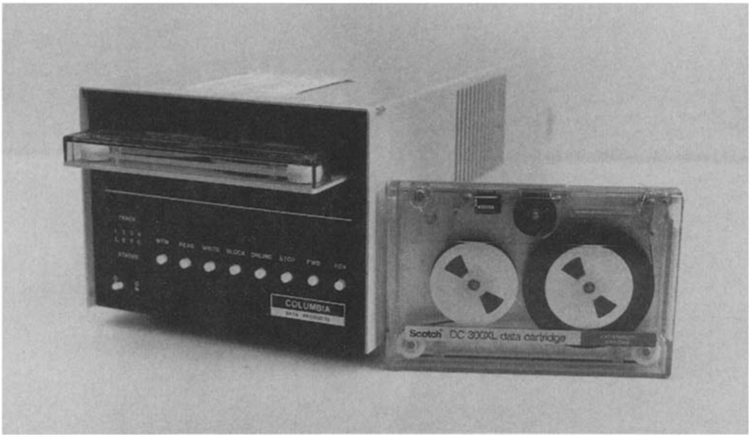


Fig. 6. Data cartridge recorder and a tape cartridge

over a 2 s period. At the end of this period, the counter, fuel flow, and implement position signals were read. The resulting analogue voltages, frequency counts and fuel flow readings were then converted to forces and rates. This information constituted a sub-block of data. These sub-blocks were accumulated and averaged until either:

(1) a maximum number of sub-blocks had been accumulated (typically 60);
(2) the operator changed gear;
(3) the three-point hitch position changed; or
(4) fuel flow changed by more than one-third its value in the first sub-block.

The resulting average of sub-blocks constituted a block of data and was stored in bubble memory, and the scanning procedure was repeated. This arrangement helped ensure that data from very different operating conditions were not averaged into the same data block.

4.2.3. *Tractor performance optimization*

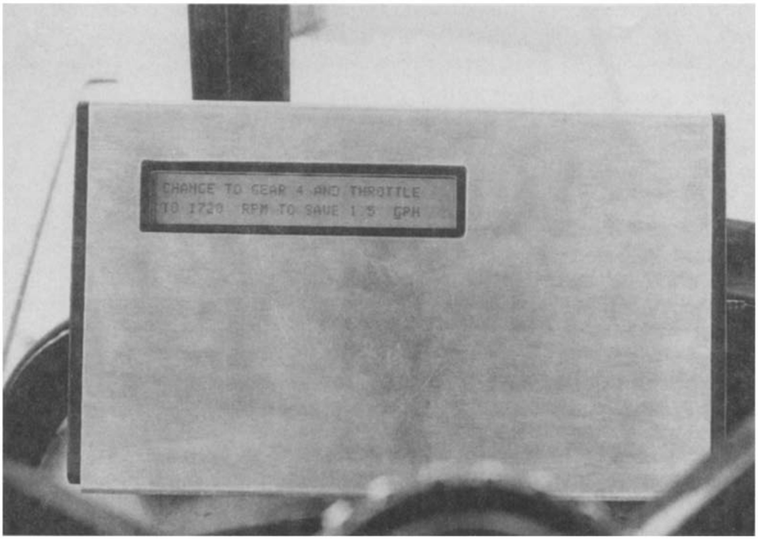
The computer optimized tractor performance by displaying operating information and suggesting gear and engine speed changes to the tractor operator. The optimum tractor gear and engine speed were determined based on the s.u.t.b. principle and a method of predicting engine performance developed by Jahns.[34]

The Jahns method establishes an empirical relationship between engine speed, engine torque and fuel flow. The mathematical model uses 17 coefficients whose values are determined from the engine performance map. Given any two of the above variables (speed, torque, fuel flow), the third can be predicted.

The information feedback monitor maintained a constantly updated display of engine speed, axle power, forward speed, and wheel slip in English or SI units (*Fig. 7*). Visual and verbal warning messages were sent to the operator if slip exceeded 20%. If the optimization monitor determined a significant decrease in fuel consumption could be achieved by s.u.t.b., verbal and visual messages were sent to the operator urging him to shift to a specified gear and reduce throttle setting to a specified engine speed (*Fig. 8*). The estimated fuel savings were also reported. The optimization function could be disabled by research personnel to collect information about normal tractor operation.

```
HP=22     ERPM=1848   GPH=3.6
    MPH =2.8      %SLIP=6   _
```

Fig. 7. Current performance display on covered Transterm terminal



```
CHANGE TO GEAR 4 AND THROTTLE
TO 1720  RPM TO SAVE 1.5  GPH
```

Fig. 8. Shiftup, throttle-back message

4.2.4. *Monitor*

The monitor program allowed research personnel to communicate with the computer via a terminal. The primary functions available through the monitor were:

(1) transfer data from bubble memory to magnetic tape;
(2) monitor real-time tractor operations—a function also useful for evaluating the condition of the instrument package;
(3) adjust the zero offsets and conversion constants on the signal conditioners;
(4) provide a summary of tractor operation since the computer was last serviced, i.e. information such as tractor start times, instrument errors, and the amount of data memory available;
(5) set the scan parameter to meet the data acquisition requirements; and
(6) test and initialize bubble memory.

5. Field testing

Commercial farmers operated the tractor during field tests. Since the first objective of the project was to gather data on tractor use on Texas farms, research personnel interfered with tractor operation as little as possible. Normally, research personnel were not present on the farm during field testing. The tractor was loaned to each farmer for several months, exposing the tractor to a variety of loading and operating conditions at each farm.

Additional information was collected to supplement the computer collected data. Farmers maintained a logbook of tractor use, field operation, operator name, soil conditions, and other information that the computer could not collect. The soil type for each field was recorded.

Periodically, research personnel inspected the tractor and the performance monitor. The instrumentation and signal conditioners were recalibrated, and any required maintenance was done. The recorded operating data were transferred from bubble memory to magnetic tape, then to a computer in the TAMU Agricultural Engineering Department for analysis.

The tractor optimization monitor was tested on a commercial farm near TAMU. The tractor was operated without information feedback, then with feedback under similar loading conditions, and the fuel consumption was compared. Additional tests were carried out with research personnel driving the tractor.

6. Data analysis

Since large quantities of data were collected, a complete analysis was performed on a minicomputer. First, data were screened to detect missing or faulty information, and the results were then reported to the analyst. After screening, the raw data listing was printed allowing the analyst to review the data.

Three principal data analyses were performed. A summary analysis computed the mean, minimum, and maximum of 26 tractor operating parameters. A gear analysis presented the tractor gear history in tabular form, showing what percentage of time the tractor was operated in each gear. This analysis was based on a procedure developed by Johnson.[35]

The third analysis was based on s.u.t.b. principles. The specific fuel consumption, defined as the fuel consumed divided by work output (g/kWh), was calculated for each block of operating data. Using the Jahns procedure, the computer predicted the specific fuel consumption (s.f.c.) had the tractor been operated in a higher gear and at a lower engine speed, while maintaining the same power output.

Predicted s.f.c. values were obtained using a model based on a performance map generated under controlled laboratory conditions. Predictably, s.f.c. field values were higher due to non-optimum engine environment and parasitic loads due to accessories. A s.f.c. correction factor (ratio between measured s.f.c. and the s.f.c. predicted by the model for the same operating conditions) was, therefore, applied to all predicted s.f.c. values.

Each field operation was analysed individually, allowing the analyst to account for field conditions, tractor load, instrument error, and other factors that could affect the analyses. All assumptions were reported with the analysed results.

7. Results and discussion

The tractor performance monitor has recorded about 60 h of usable operating data without the feedback system operational. The operating time for each implement is given in Table 1. The tractor performance monitor has generally performed well. The only computer problem was occasional difficulty in accessing bubble memory, and this has now been eliminated. The tractor instrumentation was the source of numerous minor problems which have been corrected.

A summary analysis of four field operations performed by several operators on a single

Table 1

Tractor operating data on the Lehman farm

Operation	*Time, h*
Offset disk harrow	24·65
Transport	16·92
Land leveller	6·56
Grain drill	3·71
Hay baler	3·54
Field cultivator	2·63
Fertilizer spreader	2·34
Hay rake	0·84
Total	61·19

farm is presented in Table 2 and *Fig. 9*. Table 2 represents the average operating parameters for all data collected with each implement. The parameters provide an indication of each set of tractor operating conditions.

Fig. 9 presents fuel analysis results. Point A for each implement represents the actual field operation. The points are plotted on a graph of torque versus engine speed, with percent rated power and specific fuel consumption (s.f.c.) curves superimposed. Engine operation becomes less efficient at lighter loads and higher engine speeds. Note that each field operation was performed at full throttle and light to moderate engine loads.

The B points on the performance map indicate the predicted engine operation if s.u.t.b. had been practiced. The dotted lines show that power output remained about the same while engine torque increased and engine speed was reduced. Each case shows a reduction in the s.f.c., resulting in significant fuel savings. Table 2 shows the predicted fuel savings varied from 15·6 to 27·2% or 4·4 to 5·8 l/h.

Preliminary field tests using the operator information feedback system were somewhat inconclusive because control of tractor use was difficult under commercial farm conditions. Nearly 33 h of field data were obtained using a general purpose seedbed preparation implement with the operator feedback system first disabled (18·1 h) and later enabled (14·8 h). As shown in Table 3, fuel consumption was reduced by 15·9% (3·1 kg/h) when the feedback system was used, but the power output also dropped from 50·1 to 39·1 kW, apparently due to changing field conditions which resulted in a 10·5% increase in s.f.c. The operator implemented s.u.t.b. when prompted to do so by the computer, as shown by the

Table 2

Summary analysis of four field operations on the Lehman farm

Parameter	*Field cultivator*	*Fertilizer spreader*	*Offset disk harrow*	*Land leveller*
Ground speed, km/h	7·7	13·4	7·4	6·3
Engine torque, Nm	320·0	282·4	236·8	162·2
Engine speed, rev/min	2299	2302	2298	2302
Engine power, kW	76·9	68·1	57·0	39·0
Draft, kN	15·7	1·8	19·3	9·0
Drawbar power, kW	33·6	6·5	39·8	15·8
Engine torque, Nm	319·4	282·1	236·3	161·8
Engine speed, rev/min	2299	2303	2299	2303
Engine power, %	70·0	61·9	51·8	35·5
Wheel slip, %	13·1	6·8	8·6	9·0
Fuel flow, kg/h	24·0	22·8	20·8	17·8
Engine efficiency, %	25·5	23·7	21·7	17·3
Tractive efficiency, %	49·2	10·7	79·8	46·6
Overall efficiency, %	11·1	2·2	15·2	7·0
Engine s.f.c., g/kWh	312	335	365	456
Values predicted during data analysis				
Engine s.f.c. prediction error, %	−0·2	0·3	−0·1	−0·4
Engine s.f.c. ratio using s.u.t.b.	0·96	0·97	1·02	1·21
Engine torque using s.u.t.b., Nm	417·9	378·3	309·4	210·1
Engine speed using s.u.t.b., rev/min	1848	1769	1763	1780
Engine power using s.u.t.b., kW	76·9	68·1	57·0	39·0
Engine torque using s.u.t.b., %	87·4	79·1	64·7	39·0
Engine speed using s.u.t.b., %	84·0	80·5	80·2	80·9
Engine power using s.u.t.b., %	70·0	61·9	51·8	35·5
Fuel savings using s.u.t.b., l/h	4·4	5·1	5·6	5·8
Fuel savings using s.u.t.b., %	15·6	18·9	22·4	27·2
Dollar savings using s.u.t.b., $/h	1·11	1·27	1·39	1·46

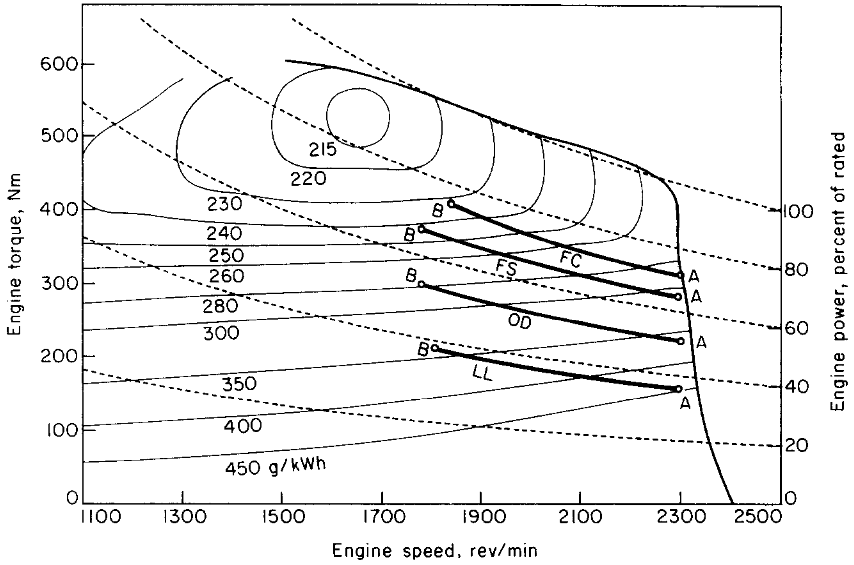


Fig. 9. JD 4440 engine performance map showing measured points at rated speed (A) and s.u.t.b. operating points (B) for several field operations. FC, field cultivator; FS, fertilizer spreader; OD, offset disk; LL, land leveller

13·9% drop in engine speed. Projected fuel savings, as determined in the data analysis procedure, dropped from 3·9 l/h with the feedback system disabled to 0·2 l/h with the feedback system enabled, which indicated that the tractor could not have been driven much more efficiently. Additional field tests were conducted under controlled circumstances to clarify these data.

The tractor was operated by research personnel in different gears and throttle settings which allowed the feedback system to generate messages which were then obeyed. Results

Table 3

Data analysis for the operator information feedback system used on a commercial farm

Parameter	*Feedback disabled*	*Feedback enabled*	*Percent changes*
Ground speed, km/h	10·6	10·9	+3·0
Axle power, kW	44·1	34·1	−22·6
Engine torque, Nm	222·6	202·3	−9·1
Engine speed, rev/min	2145	1846	−13·9
Engine power, kW	50·1	39·1	−21·8
Engine torque, %	46·5	42·3	−9·1
Engine speed, %	97·5	83·9	−13·9
Engine power, %	51·6	40·3	−21·9
Wheel slip, %	6·0	4·9	−18·9
Fuel flow, kg/h	19·4	16·3	−15·9
Engine s.f.c., g/kWh	396	438	+10·5
Projected fuel savings using s.u.t.b., l/h	3·9	0·2	−94·9
Recorded operating time, h	18·1	14·8	
Percent time unloaded	8·9	12·3	
Percent time loaded	91·1	87·7	
Number of sub-blocks averaged	22114	16463	

Table 4

Data analysis for the operator information feedback system used by research personnel under controlled conditions

Parameter	*Gear 4 before s.u.t.b*	*Gear 5 after s.u.t.b.*	*Percent change*	*Gear 5 before s.u.t.b.*	*Gear 6 after s.u.t.b.*	*Percent change*	*Gear 4 before s.u.t.b.*	*Gear 5 after s.u.t.b.*	*Percent change*
Ground speed, km/h	8·0	8·1	+1·3	10·3	10·7	+3·9	7·3	7·3	0·0
Axle power, kW	27·0	30·1	+11·5	38·4	39·3	+2·3	27·7	26·4	−4·9
Engine torque, Nm	130·5	185·1	+41·8	185·5	241·9	+30·4	144·9	181·9	+25·5
Engine speed, rev/min	2244	1752	−21·9	2233	1783	−20·2	2076	1566	−24·6
Engine power, kW	30·7	34·0	+10·7	43·4	45·2	+4·1	31·5	29·8	−5·4
Wheel slip, %	4·0	4·6	+15·0	5·0	4·8	−0·4	4·9	4·4	−10·2
Fuel flow, kg/h	15·0	13·3	−11·3	18·3	15·3	−16·4	14·5	11·6	−20·0
Engine s.f.c., g/kWh	489	391	−20·0	421	339	−19·5	459	388	−15·5
Projected fuel savings using s.u.t.b., l/h	5·8	0·0	−100·0	5·3	0·0	−100·0	4·1	0·0	−100·0
Recorded operating time, h	0·69	0·33		0·36	0·25		0·03	0·15	
Number of sub-blocks averaged	1238	590		653	443		276	48	

are included for three sets of trials (Table 4). The first two sets illustrate s.u.t.b. starting with a full throttle setting in gears 4 and 5 and then shifting up to gears 5 and 6, respectively. The third set gives an example of starting in gear 4 at a less than full throttle setting and shifting up to gear 5. The three sets show that s.u.t.b. is viable in a variety of operating conditions. Fuel savings of 11·3 to 20·0% were achieved while maintaining or slightly increasing power output and workrate as indicated by engine power and forward speed. Specific fuel consumption figures declined by 15·5 to 20·0%.

The gearshift matrix from another series of field tests (Table 5) indicated the tractor was in "park" 21% of the time, in third gear operating the grain drill 68% of the time, and in sixth gear transporting the grain drill 7% of the time. The vertical axis represents the tractor operating gear during a given sub-block period, and the horizontal axis represents the tractor gear used during the following sub-block period. Each observation in the table represents one sub-block period. For example, the gear matrix in Table 5 has a 6 located in row three and column zero, i.e. the tractor was shifted from third to zero (park) six times.

8. Conclusions

Microcomputers are an excellent tool for tractor performance monitoring and optimization. Some features of microcomputers are speed, flexibility, durability,

Table 5

Gear shift pattern while operating a grain drill

Date: May 18, 1984
Location: Lehman farm
Operator: Daniel
Sub-block period: 2 s

Time: 11.05–14.38
Implement: Grain drill (4·11 m)
Soil conditions: Good
Max block period: 2 min

Gear shift pattern

Preceding gear	*Following gear*								
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
0	839		2	7	1	1			
1	3	14	1						
2		1	5	1	1				
3	6			2723		2			
4		1			17	3			
5	1	1		1	1	75	4		
6		1			1	2	294		
7									
8									
Total	849	18	8	2732	21	83	298	0	0
Percentage	21·2	0·4	0·2	68·1	0·5	2·1	7·4	0·0	0·0
Stable state %	20·9	0·3	0·1	67·9	0·4	1·9	7·3	0·0	0·0

Total number of observations = 4009

compactness, and the ability to process and record data in the field. Bubble memory appears to be a viable method of storing large data quantities in an off-road vehicle environment.

Field tests with an instrumented tractor indicated Texas farmers often ran the tractor at full throttle and light engine loads, thereby achieving poor fuel efficiency. Research performed in other regions of the US and the world has shown similar results.

Procedures were developed to reduce massive volumes of field test data to meaningful averages and patterns such as in the gear shift table.

Predicted fuel savings by s.u.t.b. varied from 15 to 27% with four implements and several operators on a single farm. Actual fuel savings of 11·3 to 20·0% were achieved in controlled field trials.

9. Acknowledgements

The financial assistance of Deere and Company, Moline, Illinois, and the Center for Energy and Mineral Resources, TAMU, is gratefully acknowledged.

10. References

[1] **Matthews, J.** Energy management and agriculture. Energy and Farm Mechanisation. Proceedings of the First International Summer School in Agriculture. Royal Dublin Society, 1982, pp. 85–103

[2] **Ricketts, C. J.; Weber, J. A.** Tractor engine loading for field operations. ASAE Paper No. 60-606, 1960

[3] **Larsen, W. E.** Efficiency of utilization of four-wheel drive tractors. Agricultural Energy, ASAE Pub. 4-81, 1981, 417–421

[4] **Zoerb, G. C.; Kushwaha, R. L.** Gear-up throttle-down test on Saskatchewan farms. ASAE Paper No. NCR 83-101, 1983

[5] **Lyne, P. W. L.; Burt, E. C.; Meiring, P.** Effect of tire and engine parameters on efficiency. Transactions of the ASAE 1984, **27**(1): 5–7

[6] **Langewisch, S. A.** Portable, interchangeable instrumentation to measure draft and fuel consumption. M.S. thesis, Department of Agricultural Engineering, University of Missouri at Columbia

[7] **Grevis-James, I. W.** Tractor performance monitoring. Unpublished report. Dept. Agric. Engrg., Oklahoma State University, 1980

[8] **Green, M. K.** An instrumentation package for monitoring tractor performance. M.S. thesis, Department of Agricultural Engineering, Texas A & M University, 1983

[9] **Luth, H. L.; Floyd, V. G.; Heise, R. P.** Evaluating energy requirements of machines in the field. ASAE Paper No. 78-1588, 1978

[10] **Grevis-James, I. W.; Devoe, D. V.; Bloome, P. D.; Batchelder, D. G.; Lambert, D. W.** Microcomputer based data acquisition system for tractors. Transactions of the ASAE 1983, **26**(3): 692–695

[11] **Tompkins, F. D.; Wilhelm, L. R.** Instrumentation for measuring energy inputs to implements. ASAE Paper No. 81-1575, 1981

[12] **Carnegie, E. J.; Grinnell, R. R.; Richardson, N. A.** Personal computer for measuring tractor performance. ASAE Paper No. 83-1065, 1983

[13] **Harter, D. D.; Kaufman, K. R.** Microprocessor based data acquisition system for tractor tillage measurements. ASAE Paper No. 79-5026, 1979

[14] **Lin, T.; Clark, R. L.; Adsit, A. H.** A microcomputer based data acquisition system to measure performance of a small four-wheel drive tractor. ASAE Paper No. 80-5525, 1980

[15] **Wendte, K. W.; Rozeboom, H.** Data acquisition for tillage energy evaluation. ASAE Paper No. 81-1045, 1981

[16] **Hohenberger, J. G.; Alexander, P. G.** Microcomputer based data acquisition system for mobile equipment. ASAE Paper No. 81-1569, 1981

[17] **Hendrick, J. G.; Johnson, C. E.; Schafer, R. L.; Jarrell, J. D.** A microprocessor-based field data acquisition system. ASAE Paper No. 81-1577, 1981

[18] **Reynolds, W. R.; Miles, G. E.; Garner, T. H.** Microcomputer system for data acquisition and processing in the field. ASAE Paper No. 82-5510, 1982

[19] **Stange, K.; Christianson, L. L.; Thoreson, B.; Vik, B.; Alcock, R.** Portable instrumentation package for measuring tractor work. ASAE Paper No. 82-5518, 1982

[20] **Bloome, P. D.; Grevis-James, I. W.** Tractor performance monitoring. ASAE Paper No. SWR 82-102, 1982

[21] **Schrock, M. D.; Matteson, D. K.; Thompson, J. G.** A gear selection aid for agricultural tractors. ASAE Paper No. 82-5515, 1982

[22] **Grogan, J.; Morris, D. A.; Searcy, S. W.; Wiedemann, H.; Stout, B. A.** Microcomputer-based information feedback system for improving tractor efficiency. ASAE Paper No. 84-1594, 1984

[23] **Clark, J. H.; Gillespie, J. R.** Field experience with a tractor monitor. ASAE Paper No. 82-3536, 1982

[24] **Meiring, P.; Rall, M. G.** An operator-assist system to optimize tractor efficiency. ASAE Paper No. 79-1048, 1979

[25] **Mertins, K. H.; Gohlich, H.** Driver information displays—a step to optimum tractor operation. Beyond the Energy Crisis, Vol. 3. Pergamon Press, 1981, pp. 1707–1713

[26] **Philippe, D.** Personal correspondence. Renault Agriculture, 1983

[27] **Ismail, S. M.; Singh, G.; Gee-Clough, D.** A preliminary investigation of a combined slip and draught control for tractors. Journal of Agricultural Engineering Research 1981, **26:** 293–306

[28] **Chancellor, W. J.; Thai, N. C.** Automatic control of tractor engine speed and transmission ratio. ASAE Paper No. 83-1061, 1983

[29] **Harmon, K. B.; Struthers, K. D.** Electronic controls for bus, truck, and off-highway vehicle transmissions. SAE Paper No. 820909, Warrendale, PA, 1982

[30] **Morris, D. A.; Grogan, J.; Searcy, S. W.; Wiedemann, H.; Low, A. M.; Stout, B. A.** Potential fuel savings using a tractor-operator feedback system. ASAE Paper No. 84-1077, 1984

[31] **Morris, D. A.; Searcy, S. W.; Stout, B. A.** On-board tractor microcomputer system. Proceedings ASAE National Conference on Agricultural Electronics Applications 1984, pp. 151–157

[32] **Morris, D. A.** Microcomputer-based on-board tractor performance monitor. M.S. thesis. Department of Agricultural Engineering, Texas A & M University, 1984

[33] **Searcy, S. W.; Ahrens, D. A.** Making your tractor talk (implementation of speech synthesis). ASAE Paper No. 83-1089, 1983

[34] **Jahns, G.** A method of describing diesel engine performance maps. ASAE Paper No. NCR 83-101, 1983

[35] **Johnson, G. R.** A cognitive interaction analysis system. Institute of Statistics, Texas A & M University, 1981